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SUSTAINING MEMBERS

EXPLORATORY STUDY OF THE RATE OF OXYGEN CONSUMPTION BY POTATO ROOTS[1]

JOHN BUSHNELL[2,3]

In long continued field experiments on Wooster silt loam, conventional crop rotations and fertilizer applications failed to maintain good production of potatoes whereas other field crops yielded well. Field data pointed to insufficient porosity of the soil as the factor limiting the yield of the potatoes, (1).

Postulating that the need for exceptional porosity in the soil is due to some distinctive requirement, or some inefficiency of the roots in obtaining oxygen, pot tests were conducted to determine (a) if carbon dioxide accumulation interferes with oxygen absorption or impedes growth, (b) if potato roots need oxygen in exceptionally large amounts, and (c) if they absorb oxygen readily at low as well as at normal concentrations. The studies were restricted to potatoes; no direct comparisons were made with other crop plants.

The work was done during 1945-1946. Publication was deferred until all field data were reported (1).

METHODS

The studies were made with Irish Cobbler plants in gravel culture in a greenhouse. Started in compost, the plants were transplanted when about eight inches tall to three-gallon glazed jars of coarse slag (Haydite), ¼ to ½ inch in size. When transplanted the roots were rinsed free of soil, and the seed pieces carefully cut away. In the gravel they were watered with nutrient solution formulated by Kiplinger and Laurie (5). After they resumed rapid growth, the plants were sealed off at the surface of the gravel with pliable paraffine.*

Each plant jar, through its drainage aperture, was then connected to a 5-gallon bottle of nutrient solution and another of prepared gas mixture, as diagrammed in figure 1. To irrigate, the plant jar was lowered so that nutrient solution flowed to it by gravity, whereas the gas in the jar either flowed to one of the bottles or was expelled, as desired. By careful manipulation of irrigation and drainage, pressure in the jar was kept low enough to avoid leakage along the junction of the paraffine seal and the glazed surface of the jar.

To thus irrigate, some connections had to be flexible and rubber tubing was used. Diffusion of carbon dioxide through this tubing was deemed advantageous where the study was focussed on oxygen. In a test involving the presence of carbon dioxide at the roots, the rubber connections were lightly coated with pliable paraffine.

Gas mixtures were made with air from greenhouse and commercial grades of gases. Analyses for gaseous oxygen were made by absorption in Oxsorbent after removal of carbon dioxide in sodium hydroxide

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[3]The author gratefully acknowledges the assistance of C. W. Compton, who skillfully manipulated the potted plants and made all chemical analyses.
*Supplied gratis by L. Sonneborn and Sons, New York.

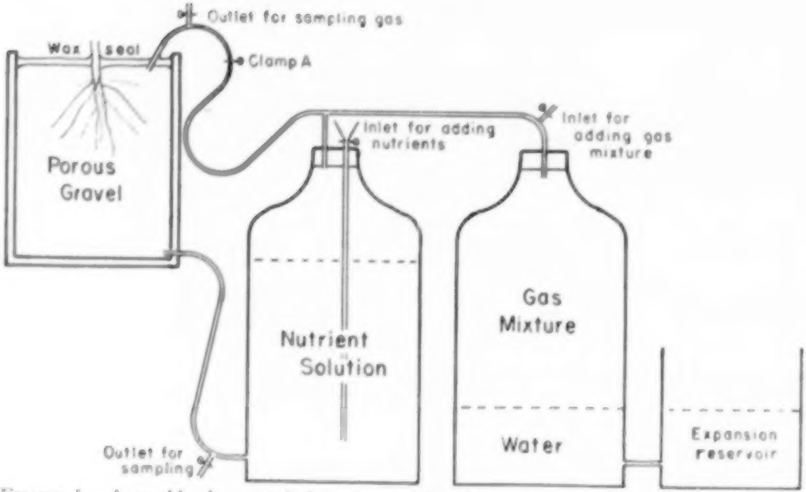

FIGURE 1.—Assembly for restricting the supply of oxygen to potato roots in gravel culture.

solution. In preliminary tests the oxygen dissolved in the nutrient solution, determined by the Winkler method, was found to be 4 p.p.m. or less. Potato roots could absorb it down to 0.4 ppm., thus obtaining about 3 mgms. to each liter of solution. As the individual plants used less than one-half liter of solution per day and drew much larger amounts of oxygen from the air, no further data were taken on the dissolved oxygen withdrawn from the nutrient solution.

Where treatment was continued for several days, it was terminated before the tubers became large enough to bulge the paraffine seal. The individual experiments were therefore, restricted to a period of a few days of the early stage of tuber development.

At the termination of each test, the roots were cut from the stems, tediously separated from adhering slag, and oven-dried. The tubers, and remainder of the plant, called "tops," were also weighed, oven dry.

EFFECTS OF CARBON DIOXIDE

The first question studied was whether the presence of carbon dioxide at the roots impeded their absorption of oxygen or affected the growth of the plant as a whole. No reports of previous experiments of this nature with potatoes were found in the literature. With other plants high concentrations of carbon dioxide at the roots have been found highly toxic, whereas concentrations likely to be encountered in soil, have been sometimes slightly toxic, and sometimes stimulating, (9).

Gas mixtures for potato roots were made up with 20 per cent of oxygen by volume and carbon dioxide at four levels: 0, 5, 10, and 15 per cent, respectively, only one plant being given each mixture. The test was conducted in a room with temperature controlled at 18.5° C., the

plants being illuminated continuously by 500-watt incandescent lamps suspended about 20 centimeters above the growing tips of the stems. Each plant was irrigated twice daily, freshly supplied each time with 3.1 liters of its gas mixture. The expelled gases were analyzed for carbon dioxide as well as oxygen. The plants grew spindly, presumably due to insufficient light. The treatments and analyses were continued for eight days.

As shown in table 1, the presence of carbon dioxide at the applied concentrations did not distinctly retard growth. On the contrary the plant with roots supplied with a gas mixture of 5 per cent carbon dioxide outgrew the others. That the treatment actually caused this vigorous growth is open to question in a single-plant test. Therefore, it might be mentioned again that similar stimulation from low concentrations of carbon dioxide has been reported with certain other plants, notably with cotton seedlings (6).

At the two higher concentrations of carbon dioxide both the growth and appearance of the tops were similar to those of the checks. The young tubers were somewhat larger and the roots smaller, but again the differences are of doubtful significance. The important point for the present study is that the rate of oxygen absorption was roughly proportional to the dry weight of the roots. In other words, when the oxygen absorption was calculated per hour per gram of dry roots, it appeared that the presence of carbon dioxide at concentrations of 10 and 15 per cent had not markedly impeded oxygen absorption.

Aside from the effects of carbon dioxide an item of interest in table 1 is the rate of oxygen consumption by the roots, or by the underground parts as a whole. If calculated as absorbed by the roots, the rate of oxygen absorption by three of the four plants exceeded eight mls. per hour per gram of dry roots. These plants, however, were growing under somewhat unfavorable conditions.

TABLE 1.—*Oxygen absorption by potato roots as influenced by CO_2 concentration.*

(Treatments Given for Eight Days.)

Gas mixtures supplied twice daily to roots	Per cent	Per cent	Per cent	Per cent
Oxygen	20.0	20.0	20.0	20.0
Carbon dioxide	0.0	5.0	10.0	15.0
CO_2 at roots found by analysis at time of gas changes, average per cent	0.4	4.9	9.1	14.1
Dry weight of plant tops, gms.	12.92	15.57	13.81	12.82
Roots, gms.	1.36	2.27	1.10	1.13
Stolons, tubers, gms.	0.22	1.30	1.00	0.58
Oxygen absorbed under surface seal during 8 days, average per hour, mls.	12.16	15.22	8.94	9.35
Oxygen absorbed per hour:				
Per gram of dried roots, mls.	8.97	6.70	8.15	8.27
Per gram of dried roots plus dried stolons and tubers, mls.	7.70	4.26	4.26	5.47

Rate of Oxygen Absorption under Very Favorable Conditions of Growth

A rate of absorption of similar magnitude to that shown by the plants of table 1 was obtained with a plant grown under particularly favorable conditions in a cool greenhouse. It was not supplied daily with fresh air, but after each irrigation the gas in its reservoir bottle was analyzed and enough oxygen added to bring the concentration up to 20 per cent by volume. The daily additions for the seven days of the test are listed in table 2.

As would be expected in a thrifily growing plant, there was an upward trend in the daily oxygen consumption during the week. In calculating the rate per gram of roots, the most valued data are those just prior to harvesting the roots. The rate the last day of the test was 7.24 mls. and the preceding day 8.07 per hour per gram of dried roots. These rates, it may be noted, lie within the range of 6.70 to 8.97 milliliters per hour shown by the plants in table 1.

These rates become of most interest when compared with oxygen consumption by other plants. The only plants similarly studied, however, were young apple trees, which Childers and White found absorbed only 7 to 12 milligrams (5.3 to 9.0 mls.) per gram of dry fibrous roots per day. (2). Therefore, their rate of consumption per day approximated the rate per *hour* of the potatoes studied here.

Oxygen Absorption of Other Plants Estimated From Respiration Studies

Before concluding that potato roots consume oxygen at an exceptionally high rate, it seems advisable to obtain some estimates for other plants, drawn from respiration studies of their roots. As a general rule in plant respiration, the carbon dioxide respired roughly equals the volume of

TABLE 2.—*Absorption of oxygen from air around roots, the amount consumed being replaced daily.*

Date of Sampling 1945	Conditions of Preceding 24 hours.			Oxygen Consumed		
	Average Hourly Temperature		Bright Sunlight	Per Day	Per Gram of Roots Per Hour*	
	Day °C	Night °C	Hours	Mls.	Mls.	Mgs.
April 27	17.3	8.4	5	480	4.94	6.38
28	12.6	8.9	0	576	5.92	7.79
29	17.7	7.4	8	512‡	5.50	7.11
30	13.5	7.2	0	560	5.76	7.37
May 1	18.3	10.2	8	640	6.58	8.41
2	18.0	10.9	9	784	8.07	10.32
3	21.1	16.7	9	704	7.24	9.36
			Average	611	6.29	8.09

*Calculated on oven-dry weight May 3: roots 4.05 grams; tops 35.4 grams; and tubers 6.1 grams.

‡Daylight saving time started April 29; only 23 hours in this daily period. For the daily average, this was calculated as 534 mls.

oxygen absorbed. With apple roots, however, White and Childers (10) pointed out that the *weight* of oxygen approximated the *weight* of carbon dioxide, and since carbon dioxide is 37.5 per cent heavier than oxygen, the *volume* of oxygen absorbed exceeded the volume of carbon dioxide respired by approximately 37 per cent. Somewhat similarly, Henderson found the roots of corn seedlings absorbed 50 per cent more oxygen than the volume of carbon dioxide given off, (4). For the estimates of table 3, the calculation was made with the simple assumption that the oxygen equalled the weight of carbon dioxide reported.

For comparison with potato roots, the data of greatest interest are those from the annual plants, mostly reported by Newton. He grew annuals in pots for 78 days, the data listed here being the respiration determinations made just before harvesting the plants and weighing the roots. His plants were thus relatively mature and respired at a slower rate than the apple roots of Childers and White. On the other hand, Reuszer reported young sunflower roots respired nearly ten times faster. This tabulation, then, indicates that previously studied annual plants consume oxygen at rates ranging from 2.7 to 30.6 milliliters per gram of dried roots per day. In contrast, potato roots studied here averaged about 8 mls. per hour, or 192 mls. per day.

A legitimate objection may be raised to the calculations of the oxygen used by potato roots, because it includes the oxygen absorbed by the tubers and stolons. The possibility that the young tubers are the exceptional absorbers of oxygen has not been experimentally ruled out, but the parallel of absorption with the weight of roots has been noted as rather better than with the weight of tubers. This is exemplified in table 1. Likewise, in the plant of table 2 the daily oxygen absorption paralleled the observed size of tops, and presumably the roots developed at similar rate. Tubers must have grown much faster; none was present when the seal was applied and eight days later their weight exceeded that of the roots. These observations point to the roots as the principal absorbers of oxygen under the seal.

A second calculation, however, is listed in table 1, based on an assumption that tubers and stolons absorb oxygen at the same rate per gram of dry matter as do the roots. The same calculation for the last two days of table 2 gives a rate of approximately 3.0 milliliters per gram of underground dry matter. These rates are still much higher than the absorption estimated for roots alone of other plants.

Absorption at Low Concentrations of Oxygen

As part of a study of the growth response from restricting the oxygen supplied to the roots, one plant was given a daily gas mixture with only 5 per cent of oxygen by volume. Analysis of the residual gas at the end of each day showed that the oxygen was regularly reduced to less than two per cent.

Further data in this direction were obtained by noting the rate at which oxygen in plant jars was depleted when not replenished nor connected to a gas reservoir. Air was introduced at the outset, — a volume of 3.1 liters at 20° C. Samples of 250 mls. were withdrawn for analysis at intervals as shown in table 4, being replaced with nitrogen. Quartz

TABLE 3.—*Estimates of oxygen absorption of roots calculated from their rate of respiration.*

Plant Studied	Author	Roots, Dry Weight	Carbon Dioxide Respired per Day per Gram of Roots		
		Gms.	Mgms.	Mls.	Mls.
Wheat	Newton (7)	1.56	6.3	3.42	4.703
Barley	" "	2.44	3.4	1.85	2.545
Peas	" "	0.59	3.6	1.95	2.70
Rape	" "	2.35	5.2	2.82	3.91
Vetch	" "	0.34	3.8	2.06	2.85
Buckwheat	" "	0.40	5.9	3.20	4.43
Alfalfa	" "	5.48	5.4	2.93	4.06
Sweet clover	" "	10.12	3.9	2.12	2.93
Sunflower	Reuszer (8)	0.60	40.8	22.2	30.6
Apricot	Harris (3)	58.7 †	5.03	2.73	3.78
Cherry	" "	103.2 †	2.89	1.57	2.17
Pear	" "	99.5 †	2.28	1.24	1.71

*At 20°C. and 760 mm. pressure.
†Mean of weight at time of grafting and at termination of 18-month test. Evidently not oven-dry weight.

gravel was used for these tests instead of water-retentive slag. The plants were irrigated twice daily, the expelled gas being returned.

The first plant of table 4, grown during a period of cool weather, withdrew so little oxygen after the concentration was down to 4 per cent that further absorption could not be measured by the technique used. In contrast, the second plant, tested during a period of high temperature, initially absorbed oxygen at the high rate of 12 milliliters per hour per gram of dry roots, and within 24 hours reduced the concentration in the jar to 0.2 per cent.

The detailed data are presented in table 4 to illustrate the decrease in rate of absorption as the concentration declined. Temperatures at time of sampling are included in this table, because some of the fluctuation in rate of absorption can be attributed to temperature. Although temperature was not a factor of study, the data also indicate that it may be a prominent factor in the rate of oxygen absorption.

DISCUSSION

Although the experiments described here were obviously exploratory, in all three approaches to the problem the roots absorbed oxygen at such a high rate that it seems reasonable to conclude that this is characteristic of potato roots. A corollary is that the plant thrives only when the roots are supplied with exceptional amounts of oxygen, and such quantities would only be expected to reach the roots in suitably porous soils.

To round out the picture, one may make an estimate of the volume of oxygen in a soil to compare with roots' consumption. A soil in good tilth, for example, and at moderate moisture content may have as much as 25 per. cent of its total volume available for air. If the air was 20 per cent oxygen, the volume of oxygen would be 5 per cent of the total

TABLE 4.—*Reduction of the oxygen content of the air in sealed plant jars.*

Date in May	Time of Sampling	Temperature in Jar	Oxygen Present	Decrease in Oxygen per Hour During Interval		Oxygen Absorbed per Gram of Roots per Hour
		°C.	Per cent	Per cent	Mls.*	Mls.
			TEST 1.—Started 8:00 A.M. May 8. Dry Weight May 10: Roots, 2.4 gms.; Tubers, 4.7 gms.			
8	10:30 A.M.	20	18.6	0.72	22.2	9.25
	12:30 A.M.	21	17.6	0.50	15.5	6.46
	2:30 P.M.	22	16.3	0.65	20.0	8.33
	4:30 P.M.	23	15.9	0.20	6.1	2.54
9	1:00 P.M.	18**	9.6	0.31	9.6	4.00
	5:00 P.M.	20	7.0	0.65	20.2	8.42
	9:00 P.M.	18	6.0	0.25	7.8	3.25
10	1:00 A.M.	16	4.8	0.30	9.3	3.88
	5:00 A.M.	14	4.0	0.20	6.2	2.58
	9:00 A.M.	13	4.0	none		
			TEST 2.—Started 6:00 A.M. May 21. Dry Weight May 22: Roots, 4.1 gms.; Tubers, 7.0 gms.			
21	9:15 A.M.	25	15.15	1.62	49.2	12.00
	1:45 P.M.	30	9.05	1.36	39.2	9.56
	5:00 P.M.	32	5.3	1.15	33.1	8.07
	9:00 P.M.	32	1.7	0.90	25.6	6.24
22	5:00 A.M.	23	0.4	0.16	4.7	1.15
	9:45 A.M.	23	0.2	0.04	1.2	0.29

**Calculated as the equivalent volume at 20° C. in a total gas volume of 3100 mls. The oxygen removed in sampling is not included.

*During the interval from May 8 to 9, the average hourly temperature was 15° C.

volume of soil. As a cubic foot is 28,317 mls. this would mean about 1400 mls. of oxygen per cubic foot. The roots of the thrifty young plants of table 2, absorbing it at the rate of 700 milliliters per day, would thus consume the oxygen of about one-half cubic foot of soil per day. Incidentally, it may be mentioned that 700 mls. of oxygen weighs close to one gram, and with 15,000 plants to the acre consuming oxygen at the rate of a gram per day, the total would be 15,000 grams or 33 pounds per acre per day.

These calculations, however, are based on a relatively young plant having roots with dry weight of only 4.06 grams. Estimated from their appearance, the roots were approximately one-third the weight that one would expect on fully developed plants.

SUMMARY

With the aim of finding a physiological reason for the sensitivity of potatoes to soil porosity, exploratory studies were made on rate of oxygen consumption by potato roots growing in pots of gravel. The

data were obtained from young plants at an early stage of tuber formation. In three tests the roots absorbed oxygen at rates ranging from 6.7 to 12.0 milliliters per hour per gram of oven-dry roots. This is a much higher rate — five to one hundred times higher — than reported for other plants or indicated by studies of root respiration.

The presence of moderate concentrations of carbon dioxide in the air around the roots did not interfere markedly with their rate of absorption of oxygen.

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THE EFFECT OF NITROGEN FERTILIZATION UPON POTATO CHIPPING QUALITY—SPECIFIC GRAVITY II.[1]

TOM EASTWOOD AND JAMES WATTS[2]

INTRODUCTION

The chip color data from this series of experiments were reported in a previous paper (1). Also, the methods employed were outlined previously. In this presentation, data upon specific gravity changes in the potato tubers will be submitted. Also, a brief summation will be included on the effects of treatments on the reducing sugar content of the tubers, chip taste, keeping quality of the tubers in curing storage, and keeping quality of the tubers in cool/cold storage.

EXPERIMENTAL RESULTS

Specific Gravity Data for Soil Culture Experiments from 1951 to 1954 and for Hydroponic Experiments from 1953 and 1954.

1. 1951 Camp Potato Experiment.

The three levels of N fertilization (2-12-12, 4-12-12, 8-12-12, at 1000 pounds per acre) had no effect upon the specific gravity of the potato tubers. This lack of response may be related to the cool season which had ample rainfall during the first half of the season and very dry weather during the second half.

However, an interaction developed between N fertilizer and potato variety. With the variety Russet Rural, the use of 40 and 80 pounds of N per acre decreased the specific gravity compared with that produced with the use of only 20 pounds per acre of N in the fertilizer. With the variety Katahdin, no differences in the specific gravity of the potatoes developed due to the three levels of N fertilization. Length of previous cold storage treatment had no influence upon the effect of N on the specific gravity of the tubers.

2. 1952 Camp Potato Experiment.

The use of the lowest application of N, 40 pounds per acre, increased the specific gravity of the tubers slightly, but not to a practical degree. Both the 80 and the 160 pounds per acre levels produced slightly lower values which were similar.

The other experimental variables, potato variety, level of potash, and the length of previous cold storage, influenced the direct N responses. This effect of potato variety (Kennebec, Nixon Seedling, Russet Rural, and White Rural) upon N response was erratic in direction.

Both the N level (40, 80, and 160 pounds per acre) and potash level (80, 120, and 160 pounds per acre) interacted to alter the specific gravity of the potatoes. This response was variable not only in direction but also in magnitude. It is apparent that the effect of increasing N applications on decreasing the specific gravity of the potatoes was more pronounced when 80 pounds per acre of potash were used than when 120 and 160 pounds per acre of potash were used.

[1] Accepted for publication February 1, 1956.

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The effect of N fertilization upon the specific gravity of the potatoes was influenced by all the possible 3-way interactions and by the 4-way interaction among the four experimental variables of potato variety, N level, potash level and length of previous cold storage. These responses indicated the difficulty of securing reliable data on the single effects of various variables, such as N fertilization, upon the specific gravity of the potato tuber.

3. 1952 Penn State Experiment

In the over-all statistical analyses, the use of 150 pounds per acre of N reduced the specific gravity of the tubers compared with the use of 75 pounds per acre of N upon the variety Katahdin.

However, this response was dependent upon the length of time the potatoes were in cold storage before they were put into the curing storage conditions for the 8 weeks' periods. From a practical standpoint the differences in specific gravity as a result of the N treatments for the 0 week and the 9 weeks previous cold storage lots were essentially ***nil***, whereas it became of practical magnitude in the lots previously in cold storage for 18 weeks.

No definite interaction developed beween N level and the potash source, muriate and sulfate of potash.

4. 1954 Penn State Experiment

No definite and consistent differences developed in the specific gravity of the potatoes as a result of four different applications of N fertilizer, using 0-160-160, 40-160-160, 80-160-160, 120-160-160, and 160-160-160 pounds of N, P_2O_5 and K_2O. The varieties under test were Katahdin, Kennebec, and Russet Rural.

5. 1953 Outdoor Hydroponic Experiment

A marked increase occurred in the specific gravity of the tubers of the potato varieties Cobbler, Katahdin, Kennebec and Russet Rural, as the nitrate concentration in the nutrient solution was raised from the low level (1.75-3.5 mm.) to the low medium level (3.5-7.0 mm.). Practically no difference showed up in the specific gravity of the potatoes from the low-medium (3.5-7.0 mm) and the medium levels (7.0-10.5 mm) of nitrate nutrient solution, whereas a noticeable increase in specific gravity occurred when the nitrate level in the nutrient solution was raised further to the high level (10.5-14.0 mm.). In every case, the specific gravity of the potatoes varied considerably among the varieties within the three upper levels of nitrate in the nutrient solution.

6. 1954 Outdoor Hydroponic Experiment

Although highly significant changes occurred in specific gravity with respect to the nitrate level (4-8, 8-12, 12-16, and 16-20 mm) in the nutrient solution, the responses were somewhat erratic It was difficult to explain the great drop in specific gravity in the potatoes grown in the nutrient solution with the medium level of nitrate. Likewise, it was difficult to explain why the very high level of nitrate in the nutrient solution produced the highest value for specific gravity in the potato tubers.

No interaction developed between potato variety (Cobbler, Katahdin, and Russet Rural) and nitrate level.

Discussion and Summary

1. The direct effects of N fertilizer upon the specific gravity of the potato tubers was erratic in direction and unclear in magnitude, depending upon other conditions. It is apparent that both rather low and rather high levels of N applications resulted in a slightly higher specific gravity than developed from the medium levels of N. Therefore in general, the direct effects of N in the ranges which supported both suitable total and graded yields exerted little practical effects upon the specific gravity of the potatoes.

2. Some of these erratic effects were caused by the interaction of the other experimental variables. The potato variety used varied in its response to the N fertilizer treatment in an erratic manner. This response was typical because the specific gravity achieved was chiefly a function of the inherent capacities of the potato variety.

3. Even the amount of potash used in the experiment altered the effect of the N fertilizer upon the changes obtained in specific gravity values. In other words, the potash level had an influence on the specific gravity of the tubers, and the relative proportion of N to K_2O also influenced the responses.

4. Sometimes the length of the cold storage before the potatoes were put into curing storage influenced the effect of N fertilizer on the specific gravity changes. In other words, the metabolic condition of the potato at different physiological ages during the cold storage life of the potatoes affected its response to curing storage influences as well as influencing the responses to N fertilizer.

5. The per cent of reducing sugar in the potatoes was not altered to any practical extent by the various N treatments in the various experiments over the period of the several years this measurement was performed.

6. The per cent of losses under the conditions of curing storage were changed very little, if any, by the different rates of N fertilizer. Also, the other experimental variables caused no interacting effects. It appears that when the N application in the field was sufficient to support adequate plant growth and yields, the quantity of N fertilizer had no essential effect on the tuber-keeping quality.

7. The amount of N fertilizer used had no influence upon the keeping quality of the potatoes when they were put into cold storage for varying lengths of time.

8. Even though the amount of data accumulated concerning chip taste quality was limited because of varying chip color, no trends were indicative of any effect of N fertilization upon the flavor of the chips.

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A LARGE INOCULATION CHAMBER WITH AUTOMATIC TEMPERATURE AND HUMIDITY CONTROLS[1]

WM. G. HOYMAN[2]

An extensive potato-breeding program has been in progress at the North Dakota Agricultural Experiment Station for several years, and recently some attention has been given to the development of potato seedlings resistant to *Phytophthora infestans*, the fungus causing late blight. To screen large seedling populations effectively during July and August, a large inoculation chamber was constructed in the greenhouse.

Figures 1, 2 and 3 show the floor plan, side A, and side C respectively, and figure 4 shows the perspective. The chamber was built over an earthen floor having the dimensions shown in figure 1. A wooden frame 13 feet long, 7½ feet wide and 6 feet in height at the eaves having a gable-type roof with approximately a 3-inch rise per lineal foot (Figure 4) was constructed to support the .005-inch plastic film and the humidity and air-conditioning equipment. A door, the relay and the humidistat were located at one end (Figure 2) and the air conditioner at the opposite end (Figure 3). Water repellent varnish was used to protect the wooden frame, and galvanized staples were used to fasten the plastic film to the frame. The plastic film on the two sides with the longest dimensions (Figure 4) was stapled at the top and to 1-inch wooden dowels at the bottom. This arrangement made it possible to roll the sides up whenever the chamber was not being used for late-blight testing and the floor space could be used for other purposes. Most of the potatoes were inoculated while growing, in flats or pots, but it was possible to plant in the earthen floor and inoculate the plants while they were growing within the chamber.

The plastic film has been very satisfactory for covering the wooden frame. Some outstanding characteristics of it are high transmission of light, resistance to tearing, low water-vapor transmission and heat-sealability.

A humidifier having an evaporation capacity of approximately ½ gallon of water per hour was suspended from the center of the roof 6 feet above the floor (Figure 4). At this location the vapor discharged from 6 holes in the humidifier dome was deposited on plants at any place on the chamber floor. Hair-element-type humidistats were not satisfactory under the high relative humidity maintained in the chamber. Very satisfactory relative humidity control has been obtained by an electronic humidistat. The heart of the controller is the sensing element which can be selected to cover any range of approximately 10 per cent relative humidity from 20 to 93 per cent. A series of elements covering ranges from 20 to 93 per cent are available. The sensing element con-

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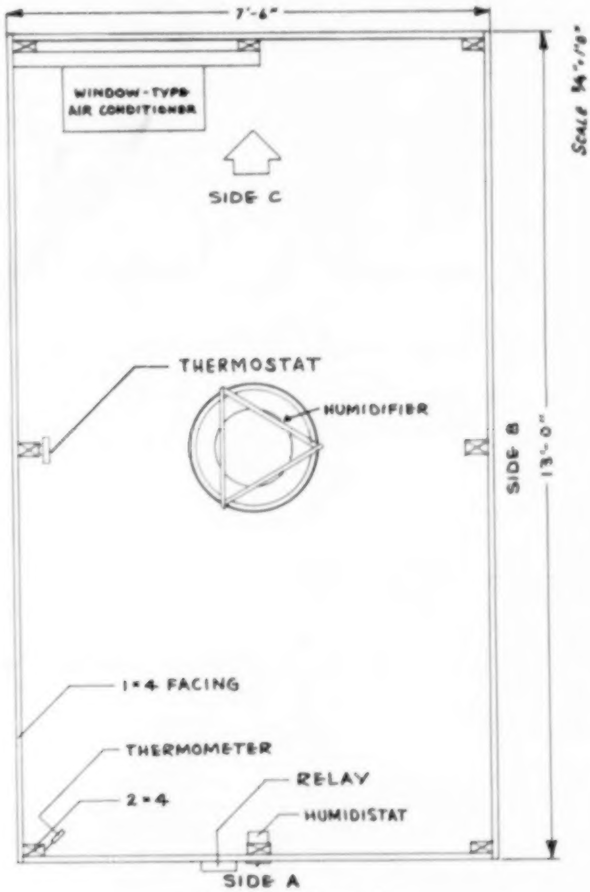

FIGURE 1.—Floor plan.

sists of a gold leaf grid embossed on a plastic base and coated with special salt and plastic.

Since the chamber was to be used extensively during July and August, it was necessary to provide conditions favorable for the late-blight fungus. Even though the greenhouse was equipped with an automatic ventilator and the glass was covered with whitewash, it was not uncommon for the greenhouse temperatures to be 100° F. or slightly over. The installation of a window-type room air conditioner (Figures 1, 3 and 4) was very satisfactory for obtaining the desired temperatures. The unit was mounted at one end (Figure 3) of the chamber 4½ feet above the floor and its operation was controlled by a thermostat mounted 1 foot above the floor at one side of the chamber (Figure 1). Chamber temperatures

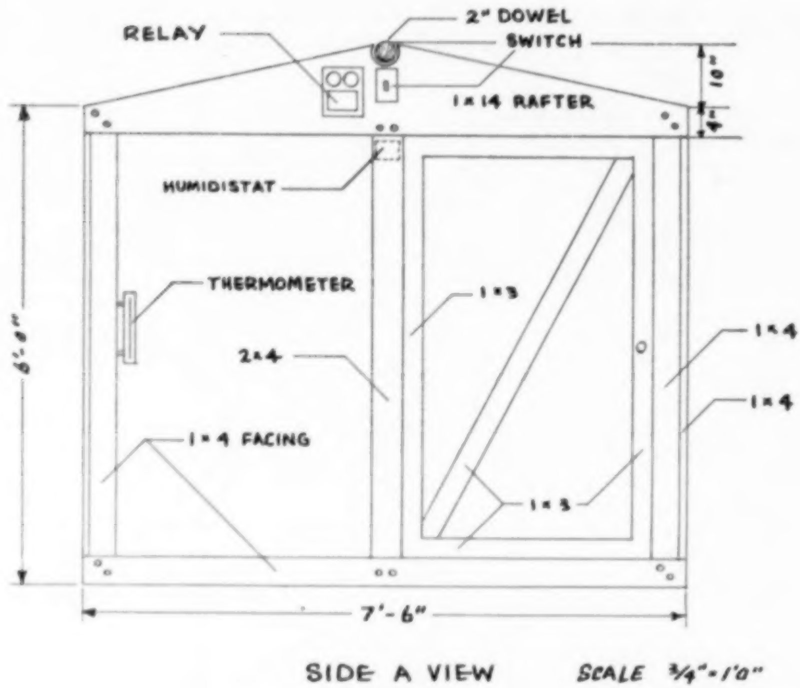

FIGURE 2.

of 68 to 72° F. were maintained when the greenhouse temperatures were slightly over 100° F. The cost of the chamber was approximately $600.

SUMMARY

A large inoculation chamber was constructed in the greenhouse in order to screen potatoes for resistance to *Phytophthora infestans*. It consisted of a wooden frame 13 feet long, 7½ feet wide and 6 feet in height at the eaves having a gable-type roof with approximately a 3-inch rise per lineal foot. The frame supported the .005-inch plastic film and the humidity and air-conditioning equipment. The temperature and relative humidity were controlled automatically with a thermostat and electronic humidistat, respectively. The cost of the chamber was approximately $600.

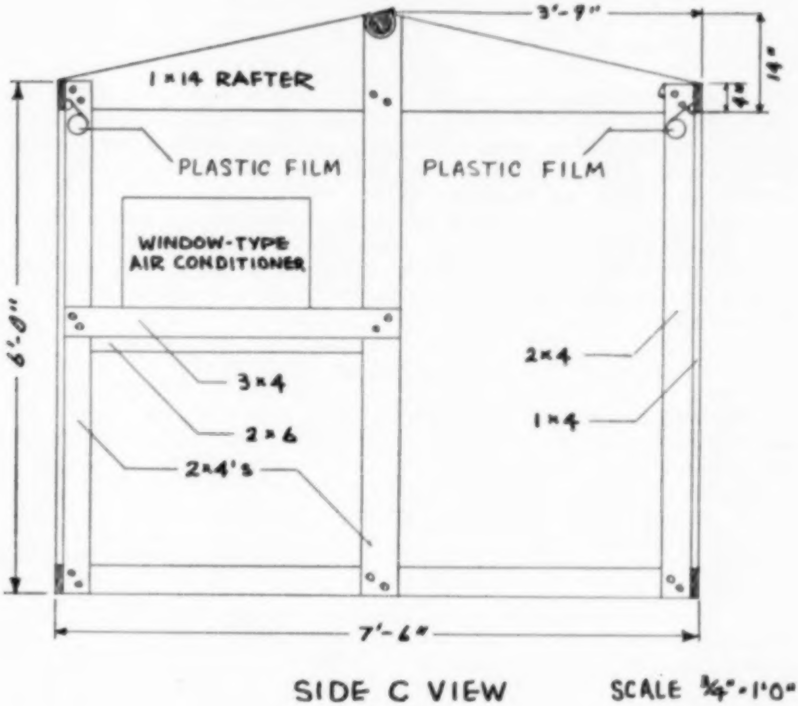

Figure 3.

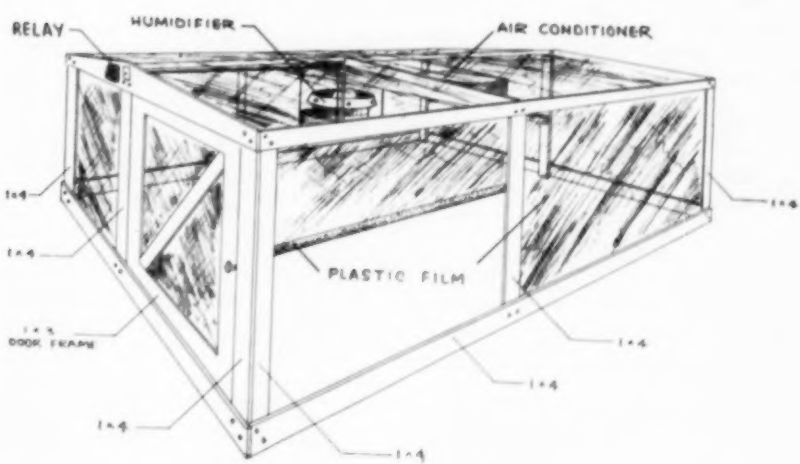

Figure 4.—Perspective.

POTATO VIRUS-S IN OREGON[1]

EDWARD K. VAUGHAN[2] AND D. H. M. VAN SLOGTEREN[3]

Since virus-S was first reported in Holland in 1951 (1), its known range has been rapidly extended. Rozendaal and Brust (4) and Larson (3) have shown that the virus is present in practically all potato-producing areas in Europe and in Wisconsin, and Gold and Oswald (2) have reported its occurrence in California.

This virus, which produces no visible symptoms on many varieties and only mild symptoms on others, reduces yields from infected plants by as much as 15 per cent. Although it is difficult to diagnose in the field, virus-S is strongly antigenic when injected into animals and is easily detected by serologic tests.

MATERIALS AND METHODS

In tests conducted in the Netherlands to determine whether virus-S was present in Oregon potato seed stocks, "eyes"' were obtained from 140 tubers. Samples of 20 "eyes" each were taken from 7 different localities in Oregon, and included 4 lots of Netted Gem and 3 of White Rose. These were grown in the glasshouses of the Laboratory for Flower Bulb Research at Lisse. When the plants were approximately 12 inches high a top and a bottom leaf from each were crushed and the expressed sap tested for virus-S.

Two types of tests were used. In the first, the undiluted crude sap was mixed with antiserum on an ordinary glass slide. In this quick test a flocculation of the chloroplasts, easily observed under the low power of a microscope after 15-30 minutes, was considered positive. This is the test used by the N. A. K. (General Netherlands Inspection Service for Seeds of Field Crops and for Seed Potatoes) in determining the presence or absence of viruses S, X and Y in more than 1,500,000 seed tubers annually.

In the second test, the remaining crude sap was diluted with an equal portion of physiologic salt solution and centrifuged for 15 minutes at 3500 r.p.m. The natent fluid was then mixed with absorbed antiserum in microdrops on Formvar treated plates (5), covered with paraffin oil to prevent dessication, incubated at 38° for 30 minutes, and checked for agglutination under the dark field microscope. This slower and more tedious test is more accurate and dependable than the rapid flocculation test.

RESULTS

All of the seed pieces, regardless of variety, source, or type of test, gave positive reactions for virus S. In similar tests all seed pieces gave

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positive reactions for Virus X, and negative reactions for Virus Y. All tests with normal serum were negative.

Discussion

Failure to find any stocks that were free from virus-S was disappointing but not too surprising since the virus is sap transmissible. In Europe, where whole small tubers are planted, greater differences in the virus content of individual seed stocks can be expected than in America where larger tubers are cut into numerous seed pieces.

The most significant results of the tests, however, was the discovery that virus-S is widespread in Oregon seed potato stocks. Since seed potatoes are shipped freely between states and between the United States and Canada, it seems reasonable to presume that virus-S is widespread in most, if not all, potato seed stocks in North America.

The senior author desires to express his sincere thanks to Dr. J. A. Milbrath and Mr. E. C. Johnson of Oregon State College for collecting and sending the potato stocks to The Netherlands, and to Dr. E. van Slogteren who so generously extended the use of the facilities of the Laboratory for Flower Bulb Research in carrying out the project.

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PREDICTION OF POTATO LATE BLIGHT INCIDENCE FROM SAMPLES OF BLIGHTED SEED TUBERS[1]

J. R. WALLIN[2]

Since the initial discovery that *Phytophthora infestans* overwinters in potato tubers (2, 6, 8) several phytopathologists have demonstrated that potato late blight will occur in potato fields planted with tubers infected with *Phytophthora infestans* (1, 3, 5, 9). Experimental results obtained in Maine (3) indicated that blighted tubers would produce blighted shoots in the field, but the diseased shoots rotted and died before the fungus sporulated upon them. However, in cull piles blighted tubers were found to produce blighted shoots upon which the fungus sporulated profusely. Therefore, blighted potato tubers in cull piles were considered as the important primary source of late blight inoculum. In Russia in 1952 (6), experimental results indicated that primary leaf infection occurred exclusively by sporangia which developed either on the surface of diseased tubers or on young sprouts in the soil. In England in 1954 (4), there was evidence that initial top infection came from tubers. The work cited indicated that blighted tubers in the field may constitute a source from which the late blight fungus will develop and spread. Therefore, the initial quantity of inoculum in a potato field may be the manifestation of the quantity of blighted tubers planted. The present study was conducted to test this hypothesis by relating the incidence of blighted tubers observed at the cutting table to the subsequent occurrence of late blight in the field.

SAMPLING TECHNIQUE

Seed potatoes were observed at cutting tables at two farms near Albert Lea, Minnesota, and at one location near Hollandale, Minnesota. The total number of tubers cut in a sample was counted and recorded. Diseased tubers culled by the cutters were examined for blight symptoms. Tubers suspected of harboring the late blight fungus were taken to the laboratory and placed in a moist chamber at 15° C. After 24 hours the cut surfaces were noted for evidence of sporulation of *Phytophthora infestans*.

FIELD OBSERVATIONS

During the ensuing growing season, fields planted to the sampled lots were observed for late blight incidence 8 times. Observations were made from the time the plants were two inches in height until harvest. The plants were about 2 inches tall on May 17 at Albert Lea and on May 27 at Hollandale. Unfortunately, in June and early July when initial late blight symptoms usually appear on the young foliage, the time intervals

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of 15 and 21 days between field surveys may have been too long to permit precise identification of the first day that late blight symptoms were obvious. Weekly observations are more desirable.

At Farms 1 and 2 at Albert Lea, cull piles were sprayed in order to eliminate them as sources of inoculum. At Hollandale the nearest cull pile was three miles from the fields under observation. Blight was found in this pile on June 24 and it was sprayed with weed killer the next day.

Results and Conclusions

The quantity of late blight diseased tubers obtained from lots of stored seed is shown in table 1.

Table 1.—*Number of late blight diseased tubers in 11 lots at three farms in southern Minnesota, and estimated late blight intensity in fields planted with sampled lots, 1955.*

Location, Variety, and Date Sampled	Bags Planted Number	Tubers in Sample Number	Blighted Tubers in Sample Number	Field Blight Intensity	Date Blight Observed
April 19					
Farm 1, Albert Lea					
Russet Burbank	150	2940	5	Slight	Sept. 8
Triumph	100	1247	0	Slight	July 26
Irish Cobbler	500	6300	46	Moderate	July 26 & Aug. 5
Kennebec	500	52800	0	None	
April 27					
Farm 2, Albert Lea					
Cherokee	2000	65098	3	None	
Kennebec	300	700	0	None	
April 27					
Farm 3, Hollandale					
Waseca	—	500	3	Moderate	July 19
Irish Cobbler	—	500	2	Slight	July 19
Red Kote	—	500	1	Trace	July 19
Pontiac	—	500	0	None	
Cherokee	—	500	0	Slight	July 19

The samples observed from the seed lots were indicative of field late blight incidence in eight of the eleven lots sampled. Obviously, the number of Triumph and Cherokee tubers sampled at Farms 1 and 3, respectively, was inadequate to identify late blight tubers. Late blight failed to develop as indicated by the sample in only one (Cherokee potatoes) of the eleven seed lots. Throughout the growing season, the Cherokee potatoes at Farm 2 had a sparse foliage growth, which, coupled with timely fungicide application and high temperature maxima in July and early August, may have limited the development of the late blight fungus so that it remained unnoticed throughout the season. However, the presence of blighted tubers in the seed lot would warn the grower to watch those fields planted to this lot. For this reason, the grower should have a pre-seasonal prediction of the fungus potential.

In an unsampled lot of Cherokee potatoes planted at Farm 2, trace amounts of late blight were found on July 26. Two limited infection centers were noted in this field.

A fungicide was applied to this field the next morning. After the fungicide application, late blight was not observed throughout the remainder of the season. Apparently the fungicide, coupled with subsequent high temperature maxima, arrested further blight development. The temperature maxima for the 7-day period from July 26 to August 1 inclusive ranged from 92° F. to 101° F. During this interval there were two nocturnal temperature-relative humidity periods, ten and twelve hours, respectively, which favored minimum sporulation and secondary infection. Probably the few spores produced were unable to establish new infection foci.

Summary

Eleven seed tuber lots at Albert Lea and Hollandale, Minnesota, were sampled for the presence of tubers with symptoms of late blight in April, 1955.

Tubers with late blight were found in two of four lots sampled at Farm 1, Albert Lea. During the season, the disease was found in two fields planted to the blighted seed lots and in one field planted to an unblighted lot.

At Farm 2, Albert Lea, late blight was not found in a field of Cherokee potatoes planted with seed whose sample yielded a trace of blight.

At Hollandale, Minnesota, tuber blight was found in three of five seed lots sampled. During the season, late blight developed in the fields planted to the blighted lots and in one field planted to Cherokee potatoes whose seed sample was blight free.

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CHEMOTHERAPY OF VERTICILLIUM WILT OF POTATOES IN CONNECTICUT 1955[1]

PAUL E. WAGGONER[2]

Verticillium wilt of potatoes has been of increasing importance in the northeast. Infection was general in Connecticut in 1955. The symptoms were seen in the majority of fields inspected in late August and September. The pathogen was isolated from 10 out of 12 fields in which isolations were attempted.

The control of wilt by use of certified seed, use of less susceptible varieties, and crop rotation has not been adequate. Therefore, in 1954 chemotherapy of this wilt was attempted in Connecticut fields (7). A growth regulator, 2,4-D (2,4-Dichlorophenoxyacetic acid), was tested because this group of compounds was known to increase resistance to another wilt disease (1). The 2,4-D treatment reduced disease symptoms and had no outstanding effects upon yields. This treatment was tested again in 1955.

Metals have decreased the severity of Verticillium wilt of mint (4) and of Fusarium wilts (5). Presumably the metals are more toxic to parasite than host and selectively kill the parasite. Uptake of metal can be increased by the use of ethlyenediaminetetraacetic acid (8). Therefore, chemotherapy by means of complexes of metals more toxic to parasite than host was attempted.

SELECTION OF TOXIC METALS

Two strains of *Verticillium albo-atrum* isolated from potato were grown on a simple medium, Czapek's, and on a more complex one, casein hydrolysate (2). One strain produced microsclerotia, the other did not. Seven days after inoculation metals were added to the cultures, with a concentration of 50 ppm. Eight days after the addition of the metals, the fungal growth was examined. Copper and aluminum as sulfates and cadmium and cobalt as chlorides were toxic to both strains in both media. Nickel, manganese, barium, and zinc were much less toxic than the above metals. Additional experiments showed the concentrations of metals that had to be added 3 days after inoculation to reduce by 50 per cent the mat grown in 11 days on the complex medium. Twenty-50 ppm of copper and aluminum, 2-11 ppm of cobalt and cadmium were required to inhibit the 2 fungi.

The toxicity of the four metals to Kennebec potatoes was tested in the greenhouse. 1000, 250, and 62 ppm solutions of the metal from ethylenediaminetetraacetic acid complex furnished by Geigy Chemical Corp. were sprayed to runoff on the leaves. The sprays were repeated 3, 6, 8, and 10 days later. Little, if any injury was seen 13 days after application on plants that had received 62 ppm of any metal. Copper and cadmium at 250 ppm caused defoliation. Cobalt and aluminum caused some spotting of leaves at 250 ppm. All metals were injurious at 1000 ppm.

[1]Accepted for publication February 13, 1956.
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Materials Used in Field

The following treatments were decided upon. Occasional sprays of metals upon plants in the field were assumed to be less toxic than repeated sprays upon plants in the greenhouse. Cobalt and cadmium complexes were applied at 500 ppm of metal. The foliage was sprayed to runoff about 40, 50, and 65 days after planting. Aluminum which was known to be present in the soil at high concentrations was applied at only 100 ppm at the same 3 times. Copper was omitted because of its known injury to potatoes. Zinc was applied because of its known beneficial effects to potatoes on some soils (3) and its known therapy of Verticillium wilt of mint (4). Zinc complex was applied as a soil drench to plots 2 feet wide. The quantity applied would produce a concentration of 33 ppm zinc in a volume 6 inches deep.

Sprays of 500 and 1000 ppm of the sodium salt of 2,4-D were applied to leaves about 40 days after planting. 250 ppm of the salt was applied to another plot about 40 and again about 50 days after planting.

Fifteen foot, single row plots of foundation stock Kennebec potatoes were planted in 3 fields known to be infested with *Verticillium*. The pH's of the soils varied from 5.2-6.0. The calcium in the soil was, in all cases, low, the aluminum medium high.

Results

No symptoms of toxicity from metal applications were found. Plants sprayed with 2,4-D were severely distorted. Unlike 1954 when recovery from 2,4-D treatment was rapid, in 1955 the plants did not recover until much later in August. The difference between the 2 years was probably caused by the severe drought in July, 1955.

Ninety-one to 103 days after planting, *i.e.*, during August, the plots were ranked for severity of wilt symptoms (Table 1). The single sprays of 2,4-D decreased symptoms significantly in 1955 similarly to symptoms observed in 1954 (7). The treatments with metal, however, had no effect with the possible exception of cadmium and aluminum in field 2.

The number of infected plants in each plot was estimated. This was done by cutting stem sections from 2 plants selected at random from each plot. The sections were surface-sterilized and incubated in an upright position on water agar at 73° F. for 7 days. We then counted the number of sections from whose vessels *Verticillium* was growing. The pathogen was identified by microscopic examination. Most of the stems were infected as shown in table 1. The treatments, even those that decreased symptom severity, did not decrease the number of infected plants.

The amount of metal in the potato stems in field 2 was determined spectrographically by Mr. W. T. Mathis 110 days after planting. Cadmium could not be detected in plants treated with that metal. A trace of cobalt was, however, detected in the treated plants. Stems from plants treated with aluminum did not contain more of that metal than did check plants. Zinc was present in the treated plants at a higher concentration than in the check plants.

The potatoes were harvested and graded. The total yield and the yield of U. S. No.1 tubers was decreased significantly by 2,4-D treatment.

TABLE 1.—*Wilt severity and per cent of stems infected by Verticillium in August in 3 experimental fields.*

	Wilt Severity				Per cent of Stems Infected			
	Field 1[a]	2	3	Mean	1	2	3	Mean
Check	6.0	6.2	4.7	5.5	100	30	88	75
1000 ppm 2,4-D	3.0	4.0	3.9	3.7*	100	60	94	86
500 " 2,4-D	1.6	3.6	4.1	3.2*	100	80	100	95
2 x 250 " 2,4-D	3.6	5.8	5.8	5.2	90	70	94	86
3 x 500 " Cd	5.4	3.3	4.5	4.4	70	60	94	77
3 x 500 " Co	5.0	6.0	4.4	5.0	90	40	94	77
3 x 100 " Al	6.0	1.7	4.3	4.0	80	80	82	81
33 " Zn	5.4	5.4	4.4	5.0	90	50	75	72

[a]Wilt symptoms were ranked in each replicate from 1 for least to 8 for most severe. severe.

[b]Five replicates were in fields 1 and 2; 8 in field 3.

That is, injury by 2,4-D exceeded the benefits of wilt symptom alleviation. Yields were not changed by treatment with metal complexes.

Discussion and Summary

The 1955 experiments verify the earlier observations that a growth regulator can decrease symptoms of Verticillium wilt of potato. In addition to this, the 1955 experiments show that the decrease in symptoms occurs without a decrease in infection. This is not surprising because growth regulators must be applied before inoculation in order to be effective (1) and their effect soon disappears (6). If a systemic fungicide can be found, chemotherapy by it will undoubtedly be more useful than the chemotherapy obtained with a regulator.

Chemotherapy, by means of fungicidal metal, was not adequately tested because the concentration was never high enough in the host stem. It remains to be seen if metal complexes can be used as systemic fungicides.

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NEWS AND REVIEWS

RESPONSE OF POTATOES TO FERTILIZER NITROGEN IN THE NORTHEAST[1]

ARTHUR HAWKINS[2]

Factors to consider in using nitrogen effectively for potatoes include (1) nitrogen requirements of the crop, (2) optimum amount to supply to obtain desired yields and quality, (3) suitability and cost of nitrogen sources, and (4) time, method of application, and placement of fertilizer for efficient production.

(1) NITROGEN REQUIREMENTS OF THE CROP

a. *Total Amount of Nitrogen Absorbed by a Crop and Quantity Removed in Tubers*:

The total amount of nitrogen absorbed by a potato crop has been found to vary considerably with the length and favorableness of the growing season and the amount of nitrogen provided by the soil and fertilizer. In Maine, Hawkins (8, 9) found that with potatoes fertilized with 100 pounds N per acre in a complete fertilizer, the total amount of nitrogen absorbed by the entire plants varied from approximately 100 pounds per acre with some varieties that died prematurely in a dry season, to about 180 pounds by some excellent stands of potatoes following clover in an exceptionally favorable season. The latter crops produced about 600 bushels of tubers per acre. At final harvest tubers contained .2 to .25 pound of nitrogen per bushel; higher amounts per bushel with lower yields. Removing the 600 bushel per acre crops removed 120 pounds N per acre or more than that applied in the fertilizer.

b. *Rate of Absorption of Nitrogen*:

Only a minor portion of the nitrogen, as well as other nutrients, is absorbed during early growth. For example, with the late variety Green Mountain in Maine only about 11 per cent of the nitrogen was absorbed during the first 50 days after planting, emergence occurring about 30 days after planting (9). The most critical period with respect to availability of large amounts of nutrients for the crop occurred about 20 to 50 days after emergence, or 50 to 80 days after planting. During this period 96 pounds or approximately two-thirds of the total nitrogen was absorbed. The crop continued to gain nitrogen until the death of the plant. Early varieties absorbed their requirements earlier than the more slowly growing late varieties.

c. *Time of Absorption and Relation to Fertilizer Practice*:

If all the supplemental nitrogen for the potato crop is applied at the time of planting, the nitrogen source should be resistant to leaching, particularly during the period when little is absorbed. (10) It should be highly available during the 30-day period after the plants are about 6 to 8 inches high. The source of nitrogen should also be available throughout the growing season since nitrogen is absorbed until the death

[1] Accepted for publication June 4, 1956.

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of the plant. Nitrogen would have to be available over a longer period in latitudes normally having a longer growing season in contrast to the shorter season in Aroostook County, Maine. On the other hand, it would also be expected that with a short growing season, late side-dressings of nitrogen would place the plant at a greater disadvantage than in regions with a longer growing season.

(2) Response of Potatoes to Rate of Nitrogen Application

The response of potatoes to applied nitrogen varies with the amount of available nitrogen in the soil, cultural methods that promote a good stand, conditions favorable for growth, and to some degree the variety. Conditions favorable for growth include favorable temperature, ample moisture supply, adequate disease and insect control, adequate supply of other nutrients and absence of toxic amounts of other elements.

With the use of the more efficient insecticides and fungicides, potato vines live longer, especially where irrigation is practiced during periods of drought, and increased response is obtained by potatoes to applied nitrogen on soils low in available nitrogen.

The response of potatoes to nitrogen on mineral soils is obviously greater on soils planted frequently to potatoes especially those low in organic matter and sandy soils subject to leaching.

Maine:

Prior to 1946 maximum response of potatoes to nitrogen on Caribou loam and other Maine potato soils was usually obtained from 80 to 120 pounds nitrogen in the fertilizer per acre, depending upon the amount of nitrogen available in the soil or cropping practice. (11) Since 1946, the use of D.D.T. and other improved disease and insect control materials has usually resulted in vines remaining green later in the season, and consequently occasional response to rates up to 180 pounds nitrogen have been obtained (25). The effect of the previous crop was marked in some of these tests (11). For example, where Katahdin potatoes followed clover or clover and ryegrass, no increase in yield was obtained with more than 90 pounds of nitrogen. In the same year at three locations where the Katahdin variety was grown on land planted to potatoes the previous year or two, however, appreciable increases in yield were obtained up to the highest amount used, 150 pounds nitrogen per acre (11).

While yields of the Katahdin variety have generally increased from applications up to 150 pounds nitrogen, either following millet or potatoes, maximum yields of the Green Mountain variety have usually been obtained with 90 to 120 pounds nitrogen in the fertilizer, particularly following legume green manure crops (25).

Although occasional yield response has been obtained in Maine to approximately 180 pounds nitrogen per acre, high rates usually cause lower quality of the tubers, both in regard to mealiness and susceptibility to skinning and bruising. Consequently the high rates are not recommended (25).

Connecticut:

Previous to the use of more efficient insecticides in 1946, Brown (1, 2, 3) found that under continuous culture on Charlton and Merrimac fine sandy loam soils, maximum yields of potatoes were obtained with

100 pounds of nitrogen per acre. In rotation where sod preceded the potatoes, maximum yields were obtained with 60 pounds or even less under the conditions which existed.

Experiments conducted on commercial potato farms in the Connecticut Valley from 1948-1952 by Hawkins and Brown (12) on soils planted frequently to potatoes, showed that with adequate disease and insect control, increased yields were obtained with increasing amounts of nitrogen, in most cases varying from approximately 150 or 180 pounds per acre.

With the use of injurious fungicides and/or inadequate insect control there was little or no response from more than 90 to 120 pounds per acre of nitrogen. Poor response was obtained on droughty soil in warm dry seasons when irrigation was not available.

During an exceptionally favorable season, at locations where the moisture holding capacity of the soil was favorable or where irrigation was used during dry periods, increased yields of potatoes were obtained with 180 and in some instances with 210 pounds of nitrogen per acre compared with lesser amounts on soils low in available nitrogen.

Response to such large amounts of applied nitrogen would not be expected where potatoes follow tobacco or on other soils higher in available nitrogen because the application of *excessive amounts of nitrogen reduces the chance for normal maturity of the crop.*

Under the longer growing season prevailing in Connecticut there was no apparent difference in the response of the two varieties, Green Mountain and Katahdin, to nitrogen when compared on the same farms in the same years.

Potato quality, as indicated by specific gravity, varied little with nitrogen rate as compared with the effect of season, location and especially varieties. In general, the use of more than 150 pounds of nitrogen per acre resulted in slightly lower dry matter content.

Rhode Island:

Odland *et al.* (19) report small increases in yield to larger applications of nitrogen up to the highest rate applied, 150 pounds per acre, on fields planted several years to potatoes. Odland and Sheehan (20) report that with potatoes grown in continuous culture on Bridgehampton silt loam since 1945, results since 1951 indicate that a total of 130 to 160 pounds of nitrogen including both the cover crop application and that applied at planting time is sufficient for the average crop.

Long Island:

On Sassafras loam on Long Island, increased yields of potatoes were obtained in most years to an additional 35 pounds of nitrogen side-dressed in addition to 140 at planting; and in some years increases were obtained at the 140 plus 70 level (23).

Up-State New York:

Meadows (15) reports small but not always significant increases in yields of potatoes grown on mineral soils to 180 pounds of nitrogen over 120, the next lower amount used, on some farm in up-state New York. With muck soils, however, he (16) obtained yield increases to 50 pounds of nitrogen only at locations that had low nitrate readings. At two

locations where soil nitrate on muck was high, applications of even 50 pounds of nitrogen tended to decrease yields.

Pennsylvania:

Merkle (17) reports results obtained on 6 farms in Pennsylvania in 1954. At those sites where considerable opportunity was afforded to maintain active organic matter during many years of crop rotation containing legumes and receiving cattle manure or poultry manure, maximum yields of potatoes were obtained with 40 pounds of nitrogen in the fertilizer. At two other sites, increased yields were obtained with 80 or more pounds of nitrogen.

Caution against Using Too Much Nitrogen for Potatoes:

Excessive application of nitrogen will delay maturity and may result in tubers lower in dry matter and more susceptible to bruising. Also lower yields may result if weather, insect and disease control are not favorable.

(3) Source of Nitrogen

Brown, Owen and Tobey (4) summarizing experiments over a sixteen-year-period in Maine, 1914-1929, found ammonium sulfate produced a higher average yield than sodium nitrate. Comparative results obtained with these two materials principally on Caribou loam was found to depend on the seasonal conditions affecting leaching of sodium nitrate during periods of heavy rainfall, or the unavailability of ammonium sulfate during periods of drought. A small increase in yield of potatoes was obtained by having part of the nitrogen in the natural organic form as compared with having it all in the form of inorganic salts.

In results from Aroostook Farm, Presque Isle, Maine, fertility plots over the period of 1927-1941, Chucka, Hawkins, and Brown (6) reported that combinations of sources such as ½ of the nitrogen from sodium nitrate and ½ from ammonium sulfate, produced higher average yields than did supplying all of the nitrogen from a single source. There was no increase in yields from the use of fishmeal to supply part of the nitrogen.

From the various Maine experiments on sources of nitrogen it was concluded that there was no advantage from using natural organic forms of nitrogen in potato fertilizers in addition to the small amounts of such materials desirable to improve the physical condition of mixed fertilizers (25).

Urea produced the highest yield as a single source of nitrogen over a six-year period as compared with nitrate of soda, sulfate of ammonia, cyanamid or fishmeal. Ammonium sulfate and ammonium chloride, both of which leave an acid residue in the soil, produced higher yields on limed than on unlimed plots (6). In Rhode Island Cox and Odland (7) found that sulfate of ammonia on the well-limed plots was much better than nitrate of soda. Odland and Moran (18) reported further evidence that sulfate of amomnia produced higher yields than did nitrate of soda.

Need for Nitrate Nitrogen:

Nine different 8-16-16 formulae varying in content of calcium, and in sources of nitrogen and magnesium were compared by Chucka *et al.* (5) in 1941 on Caribou loam at two locations in Aroostook. The formulae

without nitrate nitrogen tended to produce somewhat lower yields than did formulae with other nitrogen sources although the differences were not significant.

Under Connecticut conditions on fine sandy loam soils limed to pH 5.4 Hawkins and Brown (12) found that in complete fertilizers there were no significant differences in yields regardless of whether the nitrogen was supplied mostly from urea or sulfate of ammonia or combinations of these sources. There was no advantage in supplying part of the nitrogen in the nitrate form.

Volk and Gammon in Florida (26) found that nutritional (not virus) leaf roll apparently results when there is too little nitrate nitrogen available to produce a healthy potato plant.

Liming strongly acid soils was found to increase nitrification and help overcome leaf roll. Under Florida conditions the authors suggest supplying at least ⅓ of the fertilizer nitrogen from nitrate sources even on good soil at the proper pH value.

Nutritional leafroll was observed by the author in Connecticut following drought periods on excessively *acid areas* on two different fields, one in 1953 and one in 1955.

Acidity:

On permanent fertility plots in Maine (6) ammonium sulfate and ammonium chloride, both of which leave an acid residue in the soil, produced higher yields on limed than on unlimed plots. In Rhode Island sulfate of ammonia proved to be a slightly better source of nitrogen than nitrate of soda when the acidifying effect of the sulfate of ammonia was corrected by the addition of lime (22).

On Caribou loam in Maine, Chucka *et al.* (6) obtained as good yields with acid fertilizers as with the same mixtures rendered neutral by addition of limestone.

In Connecticut on a strongly acid soil that was low in organic matter, the use of a highly acid-forming fertilizer, resulted in lower yields when compared with the use of less acid-forming nitrogen sources (12).

The response of potatoes to the acid effect of the highly acid nitrogen source, sulfate of ammonia, is dependent upon the organic matter content as well as the pH of the soil. Liming strongly acid soils in addition to reducing the solubility of toxic aluminum will favor nitrification of ammonia and reduce the chance for nutritional leafroll associated with very low available nitrate nitrogen referred to above.

(4) Placement of Nitrogen for Potatoes

With the increase in the amount of nitrogen applied for the potato crop, comparisons have been made of methods of application of part of the nitrogen other than applying all of it in the row side-band placement.

Part Broadcast versus Side-band Placement:

Under Connecticut conditions Hawkins and Brown (12) found that when 150 or 180 pounds of nitrogen were applied for potatoes, some decreases in yield resulted on two of four farms by broadcasting 60 or 90 pounds of the nitrogen from sulfate of ammonia as compared with applying all in the row side-band placement. There was also no advantage

in yields obtained when castor pomace was broadcast to supply 60 pounds of nitrogen as compared with applying all the nitrogen in the row side bands at planting time. The reduction in yields from broadcast applications may be due to the greater leaching or to surface runoff of nitrogen.

In several tests in Maine, broadcasting 60 pounds and applying 90 in the row resulted in substantial decreases in yield as compared with applying all the nitrogen in the row at planting time (25). It was suggested that either the roots do not contact the nitrogen as well, or more nitrogen is dissolved and carried away by surface run-off than is the case with the row application.

Sidedressed Nitrogen in Comparison with All Nitrogen in Row:

In Connecticut experiments (12) ammonium nitrate applied at rates of 60 to 90 pounds of nitrogen per acre when the plants were six to ten inches high on fine sandy loam soils, kept the vines as green as when part of the nitrogen as castor pomace had been applied previous to planting, or when all the nitrogen had been applied with the complete fertilizer band placement at planting time. With all three treatments equal yields of potatoes were produced. Sidedressing with ammonium nitrate is a less expensive method of supplying nitrogen for potatoes.

In Maine, deferred application of part of the total nitrogen as a sidedressing when the plants were about twelve inches high, as compared with all of it applied at planting time resulted in decreased yields in 1949 (25). On the basis of those results it was suggested that with a short growing season, late sidedressed applications of nitrogen would place the plant at a greater disadvantage than in regions with a longer growing season (12).

Sawyer (23) reports results on Long Island that 70 pounds of nitrogen per acre in the row at planting time plus 70 as a sidedressing from ammonium nitrate shortly after emergence resulted in the same yields as 140 applied at planting time. Also there was an economic advantage from the split application.

Foliar Application of Nitrogen:

Comparisons were made in Connecticut in 1954 (14) to determine the effect of additional nitrogen on Katahdin potatoes when applied (1) as weekly applications of urea sprayed on the foliage, (2) sidedress application of either ammonium nitrate or urea when plants were 8 to 10 inches high, and (3) all-in-the-row at planting time.

At one location on a soil relatively low in available nitrogen where potatoes were fertilized with 90 pounds of nitrogen at planting time, an additional application of 60 pounds of N from urea (in eight weekly applications of 7½ pounds of N) resulted in a highly significant yield increase. The increase was about as great as was obtained from an additional 60 pounds of nitrogen applied either as a sidedressing of ammonium nitrate, or all applied in the row at planting time.

At a location where the soil was relatively very low in available nitrogen supply, the foliar applications to supply an additional 60 pounds of N resulted in an increase in yield which was not significant, but an additional 60 pounds applied sidedressed or included all-in-the-row at planting time resulted in larger and highly significant increases. At this

location potato plants showed lack of sufficient nitrogen before all the nitrogen spray treatment had been applied.

The results showed the effectiveness of a foliar application of urea as a means of supplying additional nitrogen for potatoes and that it could be used to supply additional nitrogen especially if plants are too large to sidedress.

Applying part of the nitrogen as a foliar application of urea did not produce higher yields than those obtained from equivalent amounts applied as a side dressing or included all-in-the-row at planting time.

Fertilization of Preceding Green-manure Crop versus Applying All of the Fertilizer for Potatoes:

Data obtained at Aroostook Farm, Maine, on applying all of the nitrogen for potatoes at planting as compared to applying a part for the previous green manure crop indicated that higher yields were usually obtained by applying all of the fertilizer at time of planting potatoes and that there was no advantage in applying a part for the green manure crop (24). Application of 30-60 pounds of N is usually necessary for high yields of non-leguminous crops such as Japanese millet.

In Connecticut the beneficial effects of higher rates of nitrogen fertilization of the green manure crops, rye and millet, was evident when this practice was carried on for two years and 150 pounds of nitrogen was applied for the potatoes (12).

Conclusion on Placement of Nitrogen for Potatoes

The limited *experimental* results available in the Northeast on time, method of application and placement of *nitrogen* for potatoes indicate no increases in yields from methods other than applying all the nitrogen in the row in the standard side-placement method at planting time.

However, with high rates of fertilizer, all applied in the row side bands, *greater* care must be exercised to obtain precise placement to avoid fertilizer injury to seed and sprouts, which can be *very serious primarily under dry soil conditions.* In an experiment with complete fertilizer in 1944, Smith (24) found that applying ½ the fertilizer broadcast, then plowed, plus ½ in equal-depth bands at planting time resulted in yields of 356 bushels per acre as compared with 323 when 2,400 pounds of 5-10-10 per acre were applied all in bands.

Potatoes may be fertilized effectively at less cost by sidedressing *part* of the nitrogen as ammonium nitrate or urea shortly after emergence but before they are over approximately 8 inches high. By sidedressing part of the nitrogen, less nitrogen is subject to leaching particularly on sandy soils, and the hazard of seed-piece burning and injury to the young plants is reduced as compared with applying all the nitrogen in bands at planting time.

Growers are *cautioned against using too much nitrogen. Excessive use* will delay maturity and may result in tubers lower in dry matter and more susceptible to bruising. Also lower yields may result if weather, insect and disease control are not favorable.

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The next annual meeting of the Potato Association of America will be held in conjunction with the American Phytopathological Society on December 6, 7, and 8 at the Netherland Plaza Hotel, Cincinnati 1, Ohio.

Please present titles of papers to be presented at the annual meeting to W. J. Hooker, Department of Botany and Plant Pathology, Michigan State University, East Lansing, Michigan, by October 1. It is customary to have mimeographed abstracts of these papers for distribution to the members at the annual meeting. For that reason, the abstracts should accompany the title of the paper. Otherwise, mimeographed abstracts of your paper may not be available for distribution.

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